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COMPLETE SPECIFICATION

Improvements in or relating to Well-Flow Control Devices

We, SUN OIL COMPANY a Corporation organized under the laws of the State of New Jersey, United States of America, of 1608 Walnut Street, Philadelphia 3, Pennsylvania, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to a well-flow control device useful in the production of hydrocarbons from wells, and more particularly to a tool for enabling the production of well fluids from a plurality of formations penetrated by a well, or in other words, a multiple completion tool.

In well drilling practice, a single well may penetrate a plurality of formations which contain oil or gas. It is often desirable, in such cases, to complete the well for simultaneous production from more than one of the formations penetrated. The conventional procedure for doing this is to effect a dual completion, with the flow from a lower formation or zone taking place through the well tubing, and the flow from a higher formation or zone taking place through the annulus between the tubing and casing. Chokes are provided at the surface (well head) for separately regulating the rates of flow of the the two streams, to conform to the allowable production rates for each zone.

The foregoing method of dually completing a well is unsatisfactory, for several reasons. Production through the annulus is hazardous, due to the fact that the fluid stream tends to cause corrosion and erosion of the casing, thereby allowing the possibility of a blow-out, or subterranean loss of hydrocarbons to an upper formation. Also, when it becomes necessary to utilize gas lift to effect flow from the formations, the gas lift can be applied for only one zone at a time, and that only in an efficient manner; consequently, both production strata cannot be depleted simultaneously. In many cases, this results in large quantities of otherwise recoverable oil being left in the reservoirs. A further unsatisfactory condition arises when the annulus zone (the higher zone) begins to produce salt water. Due to inefficient flow in the annulus, salt water accumulates therein, and thus loads up the well and stops the oil flow. Production from that zone then is generally abandoned. Later attempts to produce from such zone, after the other zone has become depleted, often fail to restore the production. Still another drawback in conventional dual completions is that paraffin often tends to accumulate in the annulus; such accumulations are difficult to remove.

According to the present invention there is provided a well-flow control device adapted to be positioned in well tubing for controlling the flow of a fluid into the tubing from a producing formation, comprising an outer housing having an opening for communication with the interior of said tubing; means carried by the housing for retrievably locking the same at a predetermined location in the tubing, packing means for closing the annular space between the housing and tubing above said opening, said housing having an internal flow channel extending upwardly from its opening; an inner housing having an internal fluid flow passage for communication with said flow channel and with the interior of said tubing above said packing means; means carried by the inner housing for retrievably fastening the same in position in said outer housing but allowing the withdrawal of the inner housing without the device from the well. The opening may either be across the lower end of the outer housing or be a side part.

According to another aspect of the present invention provides a flow control device comprising a main flow control device and an auxiliary flow control device which can be removed from the main flow control device without removing the latter from the well, for a well flow conductor having a longitudinal flow passage and a first lateral port communicating with the flow passage intermediate the ends thereof, the main flow control device including: an elongate mandrel positioned in the well flow conductor and provided with an internal flow passage for communicating at its upper end with the flow passage in the well flow conductor and with a second lateral port intermediate the ends of the mandrel for communicating with the exterior of the mandrel and said internal flow passage and with said first lateral port; seal means carried by the mandrel for sealing between the well flow conductor and the mandrel below said lateral ports, said mandrel having an aperture for communicating with the flow passage of the well flow conductor below the seal means; means carried by the mandrel permitting flow in one direction only into the internal flow passage of the mandrel through said second lateral port and said aperture; the auxiliary flow control device being releasably securable to the upper end of the mandrel and having means extending into said internal flow passage providing with said internal flow passage, when the auxiliary flow control device is secured to the main flow control device, a first flow passage communicating with said second lateral port of the mandrel and opening upwardly into the well flow conductor above said first lateral port and providing a second flow passage communicating with said aperture and opening upwardly into the well flow conductor.

An object of this invention is to provide new and improved means for completing a well for simultaneous production from two of more zones (a well known as a "multiple completion"), while avoiding the disadvantages of conventional dual completions, such as those described above. The construction of the device or tool of the present invention, while avoiding the disadvantages of conventional dual completions, provides additional advantages. Among the latter may be mentioned the elimination of any possibility of clogging of the chokes by foreign matter, the elimination of any possibility of erosion of tool parts by high-velocity flow through the chokes, and the improved corrosion resistance of the check valves used in the tool.

Operation of a well according to the invention involves the use of a two-part or two-piece flow control device, hereinafter described, which is positioned in the well tubing adjacent one of the producing formations Fluids from the formations pass as separate streams through the flow control device and thereafter commingle in the tubing, and flow from the tubing at the well head as at single stream. The flow control device contains choke means which, in addition to its normal production-limiting function, causes a fluid stream from a zone of high pressure to undergo a sharp pressure drop prior to commingling with another stream. The resulting pressure reduction causes or facilitates the flow of fluids from one or more of the zones of relatively low pressure.

The two-piece flow control device comprises: (1) an outer housing, which is retrievably locked at a predetermined location in the tubing (by means of a landing nipple provided in the tubing); and (2) an inner housing which is retrievably fastened in the outer housing. The outerhousing has two separate internal flow channels which are adapted to communicate, respectively, with the two producing zones or formations, and this housing mounts a check valve in each channel. The inner housing provides two separate internal fluid flow passages which communicate, respectively, with the flow channels of the outer housing, and mounted in the upper end of this inner housing are two chokes one for each fluid flow passage. For controlling the flow of fluid from a single formation or zone, the inner housing would be provided with only one fluid flow passage, and one choke.

A detailed description of the invention follows, taken in conjunction with the accompanying drawings, wherein:

Fig. 1 is a schematic representation of the device or tool of the invention in position in a well;

Figs. 2A, 2B, 2C, and 2D together constitute Fig. 2, which is a detailed view, partly in section, of the tool of the invention in its operative position, but dissociated from a well;

Fig. 3 (in two parts) is a partial view similar to Fig. 2, but showing the inner housing in its unlocked or pulling position; and

Figs. 4A, 4B, 4C, and 4D together constitute Fig. 4, which is a view similar to Fig 2 but illustrating another embodiment of the invention.

Referring first to Fig. 1, which is a somewhat schematic representation illustrating the invention, a well has a casing 10 which has been cemented in place in the usual manner. The well traverses two production zones (producing formations), illustrated as an upper Zone A and a lower Zone B, which may be either gas or oil formations. The casing has been perforated for production from both zones, as illustrated by perforations 11 adjacent Zone A and perforations 12 12 adjacent Zone B. A tubing string 13 is positioned in the casing, and the annulus therebetween is closed off near the bottom of the

tubing by means of packer 14, which latter prevents communication between the two zones by way of the casing-tubing annulus. The tubing carries a landing nipple assembly 15 (to be described in detail hereinafter) in which the outer assembly 16 of the flow control device is retrievably locked, in a manner to be described hereinafter. The landing nipple assembly 15 is positioned adjacent Zone A, and contains ports 17 (located above packer 14, and communicating with the casing-tubing annulus) for receiving fluid from this zone.

It should be apparent that another packer (not shown), similar to packer 14, would be provided above ports 17, to seal the casing-tubing annulus above these ports and to prevent the flow of fluid from Zone A to the surface by way of this annulus. Suitable packers for these casing-tubing annulus seals or closures are described in detail in United States Patent No. 3,022, 828, dated February 27, 1962.

The outer assembly or housing 16, which may be located and locked in nipple assembly 15 by means of wire line equipment, forms an annulus 18 with the landing nipple assembly 15. This outer housing contains upper side ports 19 for passage of fluid from Zone A, and lower side ports 20 for passage of fluid from Zone B. Ports 17 and 19 communicate with annulus 18, and ports 20 communicate with the interior of the tubing 13. Upper packing means 21, positioned in annulus 18 above ports 19, and lower packing means 22, positioned in annulus 18 between ports 19 and 20, prevent fluid flow along the annulus 18 and force the fluid from the upper Zone A to flow through ports 19 into housing 16; packing means 22 also forces the fluid from the lower Zone B to flow through ports 20 into housing 16.

The upper side ports 19 define one end of a first internal flow channel which extends upwardly (in outer housing 16) from such side ports. A resilient sleeve-type check valve 23 (illustrated schematically in Fig. 1, but to be described more completely in connection with Fig. 2) is positioned in this flow channel, to prevent backflow of fluid toward the upper Zone A. The lower side ports 20 define one end of a second internal flow channel which extends upwardly (in housing 16) from such side ports. A resilient sleeve-type check valve 24 is positioned in this second flow channel, to prevent backflow of fluid toward the lower Zone B.

The lower end of outer housing 16 has therein an equalizing valve member 25 which is normally in a position such as to seal the lower end of this housing. The lower end of tubing 13, below packer 14, is open or is ported, as indicated by dotted lines 27 in Fig. 1, so that fluid from Zone B can flow through casing perforations 12 and into the interior of tubing 13, as indicated by the arrows 26, and thence can flow upwardly in the tubing and through housing ports 20 and past check valve 24 into the interior of housing 16. The series of arrows 26 thus indicates the lower zone flow path.

A so-called "blast joint" 28, providing a special abrasion-resistant surface, couples the lower end of nipple assembly 15 to the adjacent section of tubing 13, in a region horizontally aligned with casing perforations 11. A flow coupling 29 couples the upper end of nipple assembly 15 to the adjacent section of tubing 13. Thus, it may be seen that the landing nipple assembly 15 in effect serves as a special section of tubing inserted in the tubing string. Fluid from Zone A flows through casing perforations 11 and into the casing-tubing annulus, as indicated by the arrows 30, and thence upwardly in this annulus and through tubing ports 17 and housing ports 19 and past check valve 23 into the interior of housing 16. The series of arrows 30 thus indicates the upper zone flow path.

Summarizing the description thus far, with the outer housing 16 run and locked in place in nipple assembly 15, production from each zone can separately enter the housing, but communication between zones is prevented by the resilient check valves 23 and 24.

An inner housing 31, which may be termed an orifice head assembly, is retrievably fastened in position in the outer housing 16, in a manner to be fully described hereinafter. The inner housing is run separately from outer housing 16, by means of wire line equipment, and seats in the running neck of the outer housing; this will become clearer as the description proceeds. The inner housing 31 forms an annulus 32 with the outer housing or assembly 16. Upper packing means 33, carried by housing 31, schematically seals annulus 32 above housing ports 19, while lower packing means 34, also carried by housing 31, seals annulus 32 below ports 19. The inner housing or orifice head assembly 31 has two separate internal fluid flow passages, each of which terminates in a respective choke bean mounted at the upper end of this assembly.

More specifically, one fluid flow passage (denoted generally by numeral 35) opens into or communicates with the interior of outer housing 16 below the lower packing means 34, as indicated by dotted lines 36. Passage 35 extends upwardly through housing 31 and terminates in a choke means (carbide-faced choke bean) 37 at the upper end of housing 31. Passage 35 thus forms a continuation of the lower Zone B flow path 26, and the production rate from the lower Zone B is controlled by choke 37.

The other of the two fluid flow passages (in inner housing 31) previously referred to

communicates with the annulus 32, as schematically illustrated at 38, extends upwardly through housing 31 (separately from passage 35), and terminates in a choke means (carbide-faced choke bean) 39 at the upper end of housing 31. Chokes 37 and 39 are parallel to each other, and they are both located at and mounted in the top of housing 31. It may be seen that fluid from the upper Zone A flows past check valve 23 into the annulus 32. The last-mentioned flow passage forms a continuation of the upper Zone A flow path 30, and the production rate from the upper Zone A is controlled by choke 39.

It may be seen, from the foregoing, that separation of the production from the two Zones A and B is maintained prior to the chokes 37 and 39, so that the initial point of commingling of the two streams is just downstream from the choke beans 37 and 39, i.e. just above these two beans. Above or downstream from the choke beans, the two fluid streams commingle, and commingled flow to the surface takes place upwardly through the tubing string 13.

The pressure at the point of commingling (just downstream from the choke beans 37 and 39), which is a function of gas-liquid ratio, production rate, and tubing size, need be only that required to lift the combined (commingled) fluids to the surface. That is to say, energy is released at this point of commingling. It is therefore possible, in many wells, for the weaker (pressure-wise) zone to enter the tubing, even though its reservoir pressure may be considerably lower than the other.

In order to determine how much each zone contributes to the combined or commingled flow stream, a separate test of one zone can first be made, by blanking off production from the other with a plugged choke bean. This determines the production rate from said one zone. A test may then be made with both zones (sands) producing, the increase in production being credited to the zone not tested separately. In order to change chokes to make such tests, or to change production chokes should this become necessary, all that is required, with the tool of this invention, is to pull the inner housing (orifice head assembly) 31, by means of wire line equipment, while leaving the outer housing 16 in place. This is a very simple wire-line operation, a routine operation in the hands of an experienced wire-line operator, and thus one which requires a minimum amount of time. When the inner housing 31 is pulled in this manner, the outer housing 16 remains in the well, separation between the zones then being maintained by means of check valves 23 and 24, and packers 21, 22, and 14.

It is pointed out that both of the chokes 37 and 39 are in the same single assembly (to wit, housing 31). It is often desirable to change the chokes controlling each of the two zones, and to do so at the same time. Utilizing the construction of this invention, this can be accomplished in one operation, by pulling the housing 31 from the well.

It is also pointed out that when the outer housing 16 is left in the well in this manner, while pulling the inner housing 31, nothing that contacts the tubing is moved or disturbed, which means that there can be no possible damage to the tubing. This feature is quite important, particularly when plastic-coated tubing is employed in the well.

When the two chokes are mounted parallel to each other and at the top of the tool, as described, the flow from the chokes is vertically upward and is unobstructed, and there are no metal surfaces exposed to the flow from the chokes (and therefore, there are no such surfaces subject to rapid erosion, with consequent failure of the tool).

Fig. 2 is a detailed view, partly in section, of the tool of the present invention, both the outer and inner housings being illustrated in their operative positions, but the casing and well being omitted for simplicity. The conformity of Figs. 1 and 2 will become apparent as the description proceeds.

The elongated outer housing 16 carries at its top a running neck 40 in which the inner housing or orifice head assembly 31 seats. This running neck is integral with or fixedly secured to the outer housing 16, this housing also having a pulling neck 41 which is slidable thereon. Latching or locking means, comprising a plurality of spaced dogs 42 which are pivotally attached to pulling neck 41, are provided for securing the outer housing 16 in place in the upper or landing nipple portion 15a of a three-part landing nipple assembly 15, which latter may be, for example, an "Otis Type S Side-Door Choke Landing Nipple Assembly". The landing nipple assembly 15 comprises the landing nipple portion 15a, previously referred to, a ported collar 15b threadedly secured at its upper end to the lower end of portion 15a, and a polish nipple 15c threadedly secured at its upper end to the lower end of collar 15b. The portion 15c is provided with threads at its lower end, for coupling to lower tubing sections (not shown) of conventional construction, while portion 15a is threadedly connected at its upper end to a conventional tubing collar 43, and by means of this latter collar to upper tubing sections (not shown) of conventional construction. The landing nipple assembly 15 is located in the tubing string as to be adjacent to Zone A (see Fig. 1).

The dogs 42 are pivotally suspended from pulling neck 41, by means of an inwardly-extending cylindrical boss at the lower end of neck 41 which fits into a matching recess provided at the upper end of each of the dogs

42. The inner surfaces of these dogs are positioned against a beveled or tapered portion of the body of housing 16, as indicated at 44, this tapered portion increasing in diameter toward its lower end. The dogs 42 move vertically with neck 41, so that the inner surfaces of the dogs are slidable on the tapered surface 44; therefore, downward movement of the dogs relative to the tapered surface 44 causes the dogs to move outwardly. Dogs 42 are adapted to enter a cylindrical recess 45 of limited length provided in the landing nipple 15a. The latching or locking means here described is quite similar to that disclosed in Miller U.S. Patent No. 2,673,614, dated March 30, 1954.

Below dogs 42, the outer housing 16 carries a set of spring-loaded keys 46 which are mounted around the housing. These keys resemble an ordinary door key and are "profiled" to match with an identically-shaped locating recess 47 machined within the bore of the landing nipple portion 15a.

Before proceeding to a description of the flow controlling portions of the tool, the operation of the landing and locking means for the outer assembly or housing, which means has just been described) will first be explained. This landing and locking means comprises means for retrievably locking the outer housing at a predetermined location in the tubing. When the outer housing 16 is ready to be inserted into the well, the same is lowered into well tubing 13 (see Fig. 1) on a wire line, by means of a suitable running tool which attaches to running neck 40. This running tool may be of a type known in the art. The running tool (not shown) grips the housing 16 in such a way that running neck 40 and pulling neck 41 are held together. In other words, the upper part of the pulling neck 41 is held higher than shown on the running neck 40 by the running tool, as the housing is lowered. This means that the dogs 42 will ride higher on the tapered portion 44 than shown in Fig. 2.

The housing with keys 46 will pass downwardly until it reaches landing nipple portion 15a, which has a recess 47 such as to match keys 46. When the outer housing 16 reaches this landing nipple portion, the spring-loaded keys 46 "select" the matching recess 47, and move outwardly into this identically-shaped recess. This prevents further lowering of the outer housing. The wire line is then manipulated in such a way that the "jars", which are run just above the running tool, impart a downward hammer action to the housing. This shears a pin within the running tool and frees the pulling neck 41 for movement downwardly, allowing the dogs 42 to fall freely and move down the tapered portion 44, into the locking position shown in Fig. 2. Upward jaring then drives the tapered portion 44 upwardly, sliding this portion upwardly against the dogs 42 and forcing them into locking position in recess 45, as shown in Fig. 2. This locks the outer housing 16 fast in landing nipple portion 15a. Additional parring upwardly then releases the running tool, which is withdrawn from the well on the wire line.

The outer housing 16 ordinarily remains in position in the well at all times, and does not ordinarily need to be removed therefrom. However, when removal thereof is necessary (for example, in order to repair or replace the check valves), the outer housing may be pulled from the well by means of a pulling tool known in the art.

The landing, or locating, and locking mechanism just described is entirely conventional, so further description thereof does not appear to be necessary. For further details of such mechanism, reference may be had to the Miller patent, previously mentioned.

The running neck 40 is hollow, as is the outer housing 16, so that a continuous bore extends from end to end (longitudinally) of this outer housing. This bore is open at its upper or running neck end, but is closed at its lower end by means of a plug or equalizing valve member 25 which carries a sealing O—ring 48 in a groove in its outer surface; O—ring 48 makes sealing contact with the inner cylindrical wall of housing 16. Member 25 is ordinarily maintained in position at the lower end of housing 16, by means of a shear pin 49 which extends through the wall of housing 16 into member 25. The normal position of member 25 (as maintained by shear pin 49) is such that O—ring 48 is located above a plurality of radially-extending ports 50 which extend through the side wall of housing 16. When it is desired to withdraw outer housing 16 from the well, a "jar" and pulling tool are lowered into the tubing by means of a wire line, and manipulated to drive member 25 downwardly so as to shear the pin 49. When pin 49 is so sheared, member 25 moves downwardly within the housing 16 a distance such that O-ring 48 moves below ports 50, thereby opening communication (by way of ports 50) between the lower end of housing 16 and the surrounding fluid. This causes an equalization of pressures between the interior and exterior of housing 16, so that housing 16 can readily move upwardly in the well, once this housing is unlocked from the landing nipple portion.

In a region of outer housing 16 above member 25, a plurality of narrow elongated slots 20 (elongated in the circumferential direction of the housing) are cut through the outer wall of this housing. These slots are made narrow (in the vertical direction) to serves as screened side ports in the wall of the outer housing; the width (vertical) dimension of these slots will be further referred to hereinafter.

Fluid from the lower Zone B (Fig. 1), which enters the casing by way of perforations 12 and which flows upwardly through tubing 13 from the lower open end thereof or from ports provided in the tubing, can flow around the outside of outer housing 16 (at the lower end of this housing) and can flow into the interior of this housing by way of the housing side ports 20. A separate internal flow channel extends upwardly from the side ports 20. This flow channel includes an annular channel 51 in outer housing 16 and a plurality of inclined bores 52, which latter communicate at their lower ends with the upper end of channel 51 and at their upper ends with the interior of housing 16.

A resilient sleeve-type check valve member 24 is positioned in annular channel 51, to prevent back-flow of fluid through side ports 20. Any downward flow of fluid in channel 51 causes the upper edge of valve 24 to move outwardly against the radially-outer side of this channel, thereby covering or sealing off ports 20 from radially-outward flow. The check valve should be constructed of a tough material, such as "Neoprene" (Registered Trade Mark), "Urethane", "Teflon" (Registered Trade Mark), etc. which is unaffected by well fluids and which has sufficient flexibility for movement of the upper edge therof outwardly against the outer side of channel 51. Such material is highly resistant to abrasion by sand or other materials which may be present in the well fluids, and is also highly resistant to corrosion by corrosive liquids which may be present in such fluids. It is pointed out that resilient check valves of this type have been proven in service to have a long life, in fact very long as compared to other types of check valves, such as metal ball-check valves.

Above bores 52, the outer housing 16 carries a packing member 22 which engages the inner cylindrical wall of polish nipple 15c, to seal off the annulus between the landing nipple assembly 15 and the outer housing 16.

Above packing member 22 the ported collar 15b is provided with a plurality of radially-extending ports 17 which provide communication between the casing-tubing annulus (see Fig. 1) and the nipple assembly-outer housing annulus 18. Fluid from the upper Zone A, which flows into the casing-tubing annulus by way of perforations 11 (Fig. 1), flows through ports 17 into annulus 18. In the vicinity of ports 17, a plurality of narrow elongated slots 19 (elongated in the circumferential direction of the housing) are cut through the outer wall of outer housing 16. These slots are made narrow (in the vertical direction) to serve as screened side ports in the wall of the outer housing; the width (vertical) dimension of these slots will be further referred to hereinafter.

A separate integral flow channel extends upwardly from the side ports 19. This flow channel includes an annular channel 53 in outer housing 16 and a plurality of inclined bores 54, which latter communicate at their lower ends with the upper end of channel 53 and at their upper ends with the interior of outer housing 16, in the region of annulus 32.

A resilient sleeve-type check valve member 23, exactly similar in construction and material to valve member 24, is positioned in annular channel 53, to prevent backflow of fluid through side ports 19.

It may be seen that valve members 23 and 24 are both carried by outer housing 16, and are thus both maintained in position even when inner housing (orifice head assembly) 31 is pulled or removed from the well, the outer housing 16 remaining in the well at this time. Therefore, separation between the two producing zones is maintained at all times, even when the chokes are being replaced for test or repair purposes.

Above ports 19, the outer housing 16 carries a packing member 21 which engages the inner cylindrical wall of landing nipple portion 15a, to seal off the annulus between the landing nipple assembly 15 and the outer housing 16.

The inner housing or orifice head assembly 31 is a member separate from outer housing 16, and is retrievably fastened in position in such outer housing in a manner to be fully described hereinafter. Housing or assembly 31 comprises an upper substantially cylindrical main body portion 55 to which is secured, as by means of weldment 56, a prong-like axial downwardly-extending tubular member 57. The interior of tubular member 57 provides the fluid flow passage 35, which was previously referred to in connection with Fig. 1. When inner housing (orifice head assembly) 31 is in position in outer housing 16, tube 57 extends downwardly within outer housing 16, this tube being smaller in outside diameter than the inside diameter of housing 16, thereby to leave an annular space 32 between this tube (portion of inner housing 31) and outer housing 16. Tube 57 extends down to a point below the ports 54, and the lower end of this tube, below the ports 54 in housing 16, is enlarged somewhat in diameter and carries a pair of O-rings 34, to provide a seal between the outer surface of this tube and the inner wall of housing 16. O-rings 34 comprise a packing means which delimits the lower end of annulus 32, and seals annulus 32 below ports 19 and 54.

The extreme lower tip of tube 57 is tapered, or made somewhat frusto-conical in configuration, to facilitate or ensure the entry of the lower end of this tube into the upper end of running neck 40 of outer housing 16, when the inner housing 31 is being run into the outer housing 16. At its tip,